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Fiber Composite Materials Technology Development

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DISCLAIMER

FIBER COMPOSITE MATERIALS TECHNOLOGY DEVELOPMENT*

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ABSTRACT

This paper summarizes the FY1980 technical accomplishments from the Lawrence Livermore National Laboratory (LLNL) for the Fiber Composite Materials Technology Development Task of the MEST Project. The task is divided into three areas: Engineering data base for flywheel design (Washington University will report this part separately) new materials evaluation, and time-dependent behavior of Kevlar composite strands.

We have formulated an epoxy matrix which can be used in composites for 120°C service with good processing and mechanical properties. Preliminary results on the time-dependent properties of the Kevlar 49/epoxy strands indicate: (1) Fatigue loading, as compared to sustained loading, drastically reduces the lifetime of a Kevlar composite; (2) the more the number of on-off load cycles, the less the lifetime; and (3) dynamic fatigue of the Kevlar composite can not be predicted by current damage theories such as Miner's Rule.

INTRODUCTION

The fiber composite materials program was initiated in late 1975 to provide the basic data base for flywheel applications. The objectives of the materials program have been to

- Develop an engineering data base on the static properties of composite materials for flywheel rotor designs.
- Study the time-dependent behavior of composites in order to predict the long-term performance of a flywheel rotor.
- Screen and develop new materials, fibers and matrices for potential flywheel applications.
- Disseminate information to the industry.

The specific technical scope and the responsible principal investigators are listed below:

- Matrix Evaluation and Formulation
  (Dr. J. Kolb, LLNL)
- Fibers & Other Special Topics
  (T. T. Chiao, R. Sherry, LLNL)
- Engineering Data On Composite Materials For Flywheel Design
  (Dr. T. H. Hahn, Washington University)

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- Time-Dependent Behavior of Composites (Dr. E. M. Wu, LLNL)
- Information Dissemination to Industry (T. T. Chiao, LLNL)

In this paper, we summarize the technical progress made by Drs. Kolb and Wu in FY1980. The engineering data base will be covered by Dr. Hahn in a separate paper.

EPOXY MATRIX FOR 120°C SERVICE

System designers prefer to operate the flywheel in a vacuum chamber at as high a pressure as possible. This, in turn, may drive the service temperature of the rotor in excess of 120°C due to friction. This year we concentrated our matrix formulation work to meet this temperature requirement.

- Formulation

We studied four cycloaliphatic diamines and six imidazoles as the curing agent for the pure diglycidyl ether of biphenol A diepoxide. The final formation selected (based on toxicity, processing factors, cured resin properties, and cost) is shown in Table 1.

Table 1. Epoxy Formulation

Base Resin	Dow DER 332
Curing Agent	Menthane Diamine
Wt. Ratio	100 Resin/24.5
Cure Cycle	2h from 23 to 150°C 2h at 150°C

- Cost and Toxicity

Based on the above ratio, the resin system cost currently is $2⁺/lb which is approximately 80¢/lb more than the typical epoxies. This is mainly due to the low volume market of the menthane diamine. According to one manufacturer, there is no reason to believe why the typical volume-price relationship should not apply to menthane diamine. Nevertheless, cost for this resin system will be a drawback for some time to come. Chemically speaking, menthane diamine, being a member of the cycloaliphatic family should be much less toxic than the aromatic diamines. This is particularly true with regard to long-term toxicity.

- Processing Considerations

From the filament winding processing point of view, the viscosity is such that it requires little or no heating at ambient temperature (0.6 to 0.9 Pa's; and the potlife is such that is is adequate for wet-bath winding (gel time of 21h for 30-g mass at 25°C and 9.5h at 40°C. For composite processing, the recommended cure schedule is to gel the structure at 90°C or less, and a full cure for 2 hours at 150°C.

- Properties Of The Cured Resin

The cured resin, based on the conditions previously described, has a glass transition temperature of 153°C, and an equilibrium water absorption of 1% (ASTM - 570). The thermal coefficient of expansion (modified ASTM 228) can be represented by bilinear lines: 51.2×10^{-6} cm/cm/°C from 220 to 301K; 59×10^{-6} from 301 to 450K. The thermal conductivity (W/m·K) is 0.164 at 305K, 0.181 at 341K, and 0.218 at 418K.

The mechanical properties of the cured resin are summarized in Table 2.

Table 2. Mechanical Properties of the Cured Dow DER 332/MNDA

Tensile Properties	25°C	75°C	125°C
Modulus, GPa	2.8	2.4	1.9
Failure Stress, MPa	97.3	75.3	48.9
Failure Strain, %	7.0	6.4	6.9
Compressive Properties			
Stress at Max., MPa	124.2		
Compressive Modulus, GPa	0.04		
Strain at Max., %	6.4		
Shear Properties			
Failure Stress, MPa	62		
Shear Modulus			

Additional tests such as aging at 125°C in air and argon, and composite properties are in progress.

TIME DEPENDENT PROPERTIES OF KEVLAR 49/EPOXY COMPOSITE

Stress-rupture data of several composites have been summarized and published previously. Other than for the E-glass/epoxy composite, we consider that available data are adequate. Ongoing experiments using E-glass/epoxy strands are continuing at relatively low stress levels which have produced only few data points this year. In this paper, we summarize only Dr. Wu's work on Kevlar 49/epoxy strands in the area of stress-rupture and dynamic fatigue under tension.

The strand specimens are the basic building blocks for any flywheel designs. In our tensile stress-rupture and cyclic fatigue tests, fiber rupture controls the mode of failure of the specimens. We used Kevlar 49/epoxy strands from the same population to study the effect of load history on the lifetime of the composites. Preliminary data are summarized in Figures 1-3. In Figure 4 we compared the different load histories to show the trend.

Stress-rupture experiments were carried out under different constant tensions. This is essentially a one-cycle static fatigue test. Cyclic fatigue data were collected using square waves at different loading and resting ratios. Fatigue lifetime is the summation of all the times under load. From the data shown in Figures 1-4, preliminary conclusions are as follows:

- At a constant applied stress, cyclic loading is much more severe than sustained loading in damaging (in terms of drastically reduced lifetime) the longitudinal Kevlar 49/epoxy composite. (See Figures 1 and 2)
- The length of the rest periods in cyclic fatigue may also be an important factor affecting the lifetime of the longitudinal Kevlar composite. (See Figures 2, 3 and 4)
- Dynamic fatigue of longitudinal Kevlar composite can not be predicted by such conventional theories as Miner's Rule. (See Figures 2 and 3)

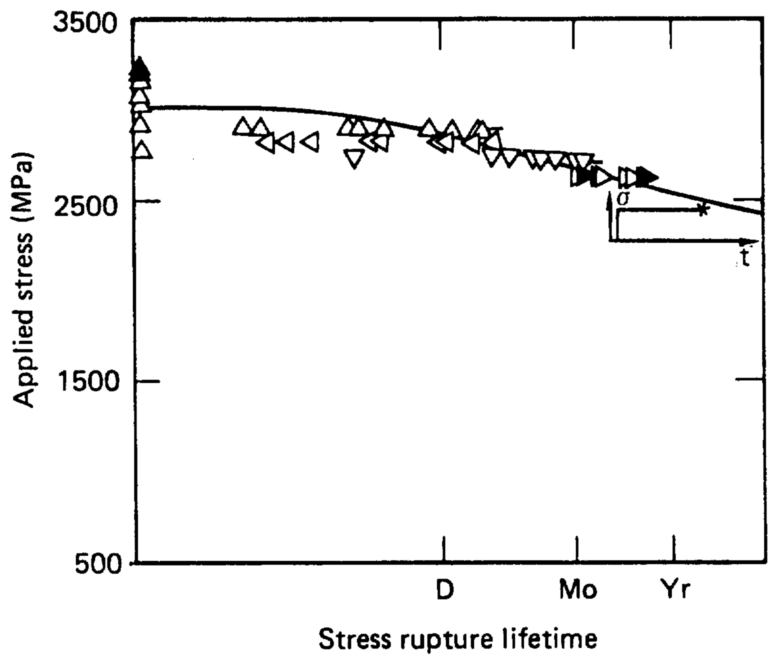

Fig. 1 Lifetime of Kevlar 49/Epoxy Strands Under Sustained Load

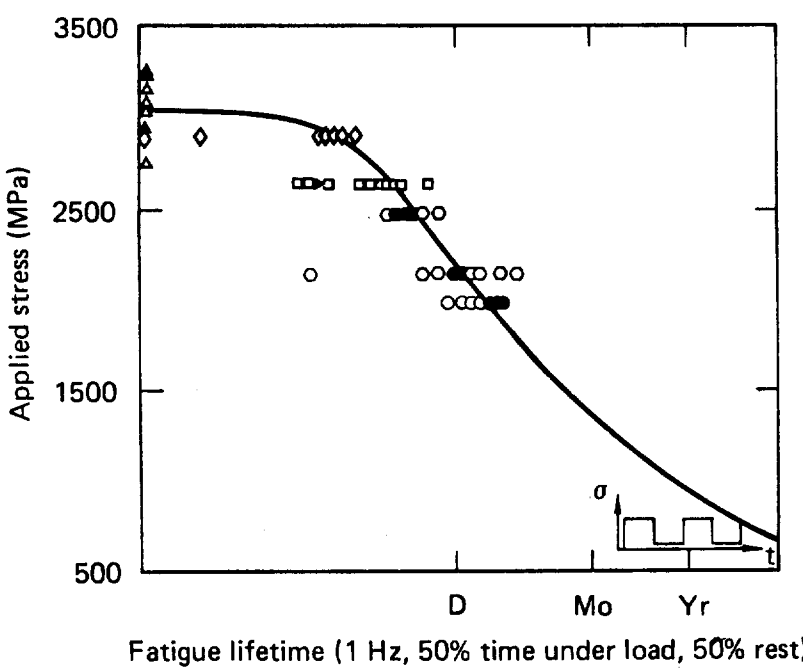

Fig. 2 Lifetime of Kevlar 49/Epoxy Strands Under Another Cyclic Load Conditions

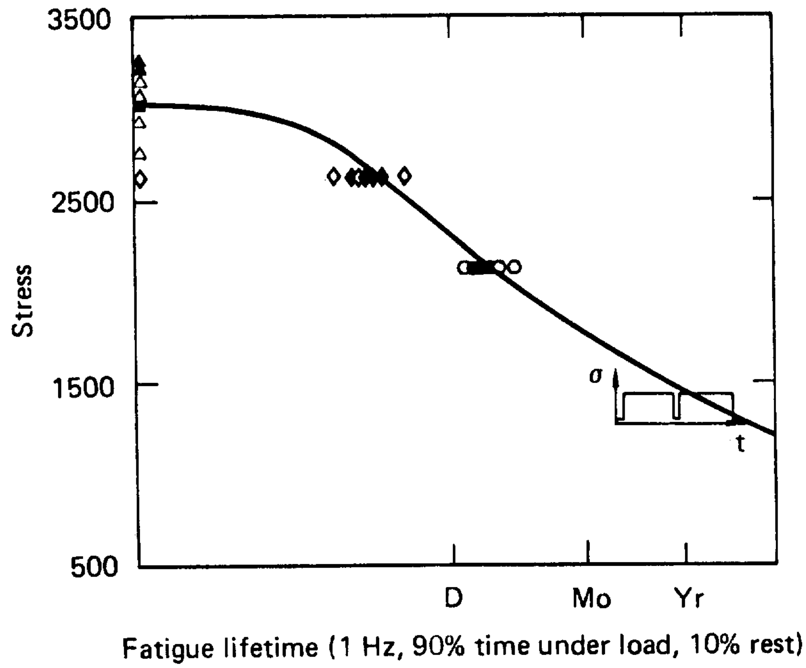

Fig. 3 Lifetime of Kevlar 49/Epoxy Strands Under One Cyclic Load Conditions

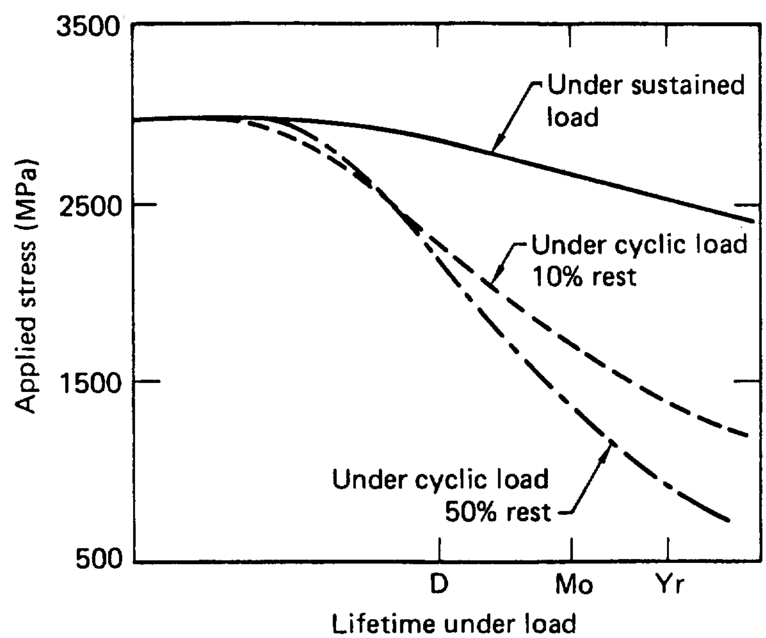

Fig. 4 Lifetime of Kevlar 49/Epoxy Strands Under Different Loading Conditions

FUTURE PLAN

A multi-year plan of the fiber composite material program has been completed, reviewed with industrial and government representatives, and finalized. We will put it into practice in FY1981.